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Fighter/Attack Automatic Collision Avoidance Systems Business Case

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//signed//

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14. ABSTRACT
This report was done on behalf of the Defense Safety Oversight Council Aviation Safety Improvements Task Force, Safety Technology Working Group. This study concludes that implementation of Automatic Collision Avoidance Systems (Auto-CAS) in F-16, F/A-18, F/A-22, and F-35 aircraft would save aircrew lives and preserve, and enhance combat capability.

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Auto-CAS, Auto-GCAS, Midair Collision, System Failure, Controlled Flight Into Terrain (CFIT)

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EXECUTIVE SUMMARY

This study concludes that implementation of Automatic Collision Avoidance Systems (Auto-CAS) in F-16, F/A-18, F/A-22, and F-35 aircraft would save aircrew lives and preserve, and enhance combat capability.

In May of 2003 Secretary of Defense Rumsfeld established a goal of 50% reduction in Department of Defense mishaps. To accomplish this goal Dr. Chu, Undersecretary of Defense for Personnel and Readiness established a Defense Safety Oversight Council (DSOC). The DSOC further chartered nine Task Force teams targeting multiple areas where mishap reduction could occur. One task force, the Aviation Safety Improvement Task Force (ASI TF) was chartered with reducing aviation mishaps. The ASI TF formed IPTs and working groups to assess aviation mishaps and recommend feasible and effective mitigation strategies. The Safety Technology Working Group (STWG) was the ASI TF working group charged with identifying technological mitigation strategies for aviation mishap reduction. This report is the result of efforts by the ASI TF STWG in assessing technological solutions to ground and airborne collision mishaps.

The historical record for United States Department of Defense (DoD) aviation assets demonstrates that controlled flight into terrain (CFIT) is the leading cause for loss of lives, lost combat capability and dollar cost. Additionally, midair collisions (MIDAIR) rank as the fifth most costly type of mishap in terms of lives, lost combat capability, and dollars (Reference 1). Likewise CFIT and MIDAIR mishaps have been particularly costly to the DOD fighter/attack (F/A) aircraft community. In the fiscal years 1992 to 2004 USAF, USN, and USMC F/A CFIT and MIDAIR mishaps accounted for 86 pilot fatalities and approximately 9 squadrons (161) of destroyed F/A aircraft ($3.7B in aircraft assets). To put this in context, about 28% of all USAF/USN/USMC pilot fatalities, and 23% of all destroyed aircraft in the fiscal years 1992 to 2004 were due to CFIT and MIDAIR mishaps.

The primary means to mitigate these losses in the past have been training and collision warning technologies (i.e., GPWS, TAWS, LASTE, PGCAS & TCAS). Training has had some success in reducing CFIT and MIDAIR rates in the past, but reductions in the rates have long been stagnant and no large improvements from training are envisioned for the future. Ground Collision Avoidance Systems like the Navy's Terrain Awareness Warning System (TAWS) in the F/A-18 and the Air Force's Predictive Ground Collision Avoidance System (PGCAS) in the F-16 provide timely warnings and directions on avoiding CFIT. However, both the Navy TAWS and the AF's PGCAS are manual systems requiring the pilot to maneuver the aircraft to avoid the collision. These systems may have had some success in reducing CFIT mishaps, but the magnitude of their improvement is not enough to achieve statistical significance. The human being is now the limiting factor because he or she cannot always recognize a warning or respond appropriately to prevent a mishap.

Airborne Collision Avoidance Systems for civilian aircraft have been developed that use cooperating radar beacon transponders to provide traffic advisories and recommended escape maneuvers. The current version used by civil and some military cargo/passenger aircraft is the Traffic Alert and Collision Avoidance System II (TCAS II). Both the Air Force (Enhanced

TCAS) and Navy (MCAS) are pursuing extensions of the TCAS methodology for more demanding tactical operations but all of these are manual systems and, just as in the Ground Collision Avoidance Systems above, the human operator is now the limiting factor.

Any future substantial reductions in F/A CFIT and MIDAIR rates require extending the collision avoidance technology to systems that not only warn the pilot but also take control and fly the aircraft out of danger before returning control to the pilot. The Air Force has developed and extensively tested on the F-16, the Automatic Ground Collision Avoidance System (Auto-GCAS). The Air Force Materiel Command (AFMC) has validated Auto-GCAS as a mature technology (Reference 2). The Navy is exploring expanding the capability of TAWS to include Auto Recovery, which will automatically recover the aircraft and return control to the pilot.

A prototype Automatic Airborne Collision Avoidance System (Auto-ACAS) to reduce MIDAIR mishaps was successfully flight tested in 2003. That system was developed by the Air Force Research Laboratory (AFRL) building on their Auto-GCAS experience. The principles and technological feasibility have been demonstrated; however, additional work remains to fully develop and integrate onto specific platforms tailored to specific mission requirements.

Projections of savings in lives, airframes, and dollars that Auto-CAS could provide to the F/A-22, F-35, F-16, and F/A-18 fleets were calculated by applying historical CFIT and MIDAIR rates to the estimated remaining service life for each aircraft type. These estimations will be conservative if any extension of service life is applied to one of these airframes because extensions will increase the exposure of the fleet to mishaps. Service life extensions would serve to make the case for these Auto-CAS systems even more compelling. The estimated savings for the F/A-22 over the fiscal years 2011 to 2035 are about 7 pilots and 13 aircraft ($1.6B in aircraft assets). For the USAF F-35 the savings over the same fiscal years amount to 52 pilots and 102 aircraft ($4.1B in aircraft assets). If Auto-CAS were fully implemented on the F-16 in the fiscal years 2011 to 2025 an estimated 13 pilots and 26 aircraft ($924M in aircraft assets) would be saved. Projections for the F/A-18 over the fiscal years 2008 to 2032 show that 6 pilots, 8 aircraft ($665M in aircraft assets) would be saved.

In summary, if completely implemented on the four fighter/attack aircraft, Auto-CAS could save approximately 78 pilots and 150 aircraft ($7.3B in aircraft assets) while corresponding implementation costs are estimated as 1.07 billon dollars. The resulting return on investment (ROI) is at least $6 to $1. These numbers argue very strongly for fielding Auto-CAS in all F/A-22 and F-35 aircraft and possibly later models of F-16 and F/A-18 aircraft. If Auto-CAS is not implemented on these four aircraft, the losses to CFIT and MIDAIR mishaps will roughly average 4 pilots and 7 aircraft ($330M in aircraft assets) a year for the F/A community.

Given the projected substantial savings with an ROI of at least $6.8 to $1 in aircraft assets and at least 78 pilot lives, it is recommended that a Joint Auto-CAS policy and program be established that would:

a) Initiate a risk reduction program to refine the requirements for, and integrate, Auto-CAS into F/A aircraft.

b) Establish overarching and top-level functional requirements for automatic collision avoidance systems.

c) Direct the services to integrate Auto-CAS capabilities in F/A-22, F-35, F-16, and F/A-18 aircraft leveraging Auto-GCAS, US Navy TAWS, Auto-ACAS, and other civil and military CAS development efforts.

d) Continue integrating manual systems into platforms where automated systems are not practical.

I. ASSUMPTIONS

The historical data used in this study will include only Class A mishaps in Air Force, Navy, and Marine fighter/attack aircraft in the fiscal years of 1992-2004. Class A mishaps are those that resulted in loss of life or over $1,000,000 in damage.

The study will only cover mishaps that could be prevented by Automatic Collision Avoidance Systems (Auto-CAS). To properly identify all the mishaps that Auto-CAS could prevent requires reviewing military aviation safety databases primarily for mishaps that have been designated as controlled flight into terrain (CFIT) or midair collision (MIDAIR). Besides CFIT and MIDAIR mishaps, there have been mishaps in which the F/A pilot suffered from G-induced loss of consciousness (GLOC) leading to crashes into terrain, which an Auto-CAS could have prevented. A fourth category of mishap, loss-of-control in-flight (LOCI), was found to contain some mishaps that Auto-CAS could have prevented.

In November 2004, the Aviation Safety Improvement Task Force, consisting of representatives from all the services, adopted standard definitions to be used by the services in classifying aviation mishaps. Those definitions appear in Attachment 1 and the main ones of interest for this study now follow.

CFIT is defined as collision with terrain, water, trees or a man-made obstacle during flight prior to planned touchdown. CFIT includes mishaps where the aircraft or unmanned aerial vehicle (UAV) is controllable and the pilot is actively controlling the aircraft/UAV or the pilot's ability to control the aircraft/UAV is reduced due to spatial disorientation (SD). CFIT also includes mishaps where the aircraft/UAV is flown in controlled flight to a point where it is no longer possible to avoid unintended ground impact (e.g., attempted maneuver with insufficient altitude or airspeed, low altitude over bank or flight into a box canyon), regardless of subsequent pilot reaction (e.g., add power, maneuver to avoid terrain, etc.).

Midair collision (MIDAIR) is defined as collision between aircraft or UAV when intent for flight exists. It includes inadvertent contact during formation, takeoffs and air-refueling operations.

The physiological (PHYSIO) type of mishap is defined as injury, illness, or abnormal symptoms experienced by aircrew or others as a result of the dynamic flight environment. It includes spatial disorientation that does not result in MIDAIR or CFIT, as well as all G-induced loss of consciousness (GLOC), hypoxia, and other physiological events.

Pilot loss of control in-flight (PLOCI) is defined as aircrew failure to maintain control of the aircraft or UAV while in flight. It includes mishaps resulting from failure to control the aircraft/UAV during flight, when that loss of control is not primarily related to environment, weather or any system failure. PLOCI includes departures, stalls and spins but it also includes some non-stall spin events. Before the standardization of this definition in November, 2004, this type of mishap was often coded in data bases as loss of control in-flight (LOCI). While it would appear from this definition that PLOCI or LOCI coded mishaps should not be considered for this

study, careful scrutiny of some of those mishaps have shown a few that an Auto-CAS could have prevented and which probably should have been listed as CFIT or MIDAIR mishaps.

For the rest of the report the term "CFIT" will be used generically to denote those CFIT, PHYSIO, PLOCI, and LOCI F/A mishaps that could have been prevented by an Auto-CAS system.

II. DESCRIPTION OF THE CURRENT SITUATION

A. THE HISTORICAL RECORD

Historically CFIT and MIDAIR mishaps have cost military aviation a great deal in lives and money. The need to reduce CFIT and MIDAIR type mishaps has been studied and reported on by both civilian and military safety organizations many times in the past.

Table 1 is from Air Force Safety Center and Naval Safety Center data of F/A aircraft for the fiscal years (FY) 1992 to 2004. The table compares F/A CFIT and MIDAIR mishaps to all Class A mishaps. See Attachments 2 and 3 for the complete data sets.

Table 1
Joint Fighter Attack CFIT and MIDAIR Mishaps Comparison to All Class A Mishaps

USAF/USN/USMC FLIGHT MISHAPS FY92-04 ALL AIRCRAFT	AIR FORCE	NAVY/MC	JOINT
Total Class A Mishaps	406	442	848
Total All Fatalities	362	421	783
Total Pilot Fatalities	126	179	305
Total Destroyed Aircraft	319	385	704
Total Flight Hours	29,491,960	20,758,952	50,250,912
FIGHTER/ATTACK * COMBINED CFIT AND MIDAIR MISHAPS FY92-04**			
F/A All Class A Mishaps	246	249	495
F/A CFIT and MIDAIR Mishaps	85	53	138
F/A All Fatalities CFIT and MIDAIR Mishaps	77	71	148
F/A Pilot Fatalities CFIT and MIDAIR Mishaps	51	35	86
F/A Destroyed Aircraft CFIT and MIDAIR Mishaps	101	60	161
F/A Flight Hours	9,230,593	6,254,929	15,485,522
F/A CFIT and MIDAIR Mishap Cost (Aircraft)	$1,903,494,388	$1,845,728,883	$3,749,223,271
FIGHTER/ATTACK vs. ALL COMPARISONS (PERCENTAGES)			
F/A Class A Mishaps vs. Total Class A Mishaps	60.59%	56.33%	58.37%
F/A CFIT and MIDAIR Mishaps vs. Total Class A Mishaps	20.94%	11.99%	16.27%
F/A CFIT and MIDAIR Fatalities vs. Total Fatalities	21.27%	16.86%	18.90%
F/A CFIT and MIDAIR Pilot Fatalities vs. Total Pilot Fatalities	40.48%	19.55%	28.20%
F/A CFIT and MIDAIR Destroyed Aircraft vs. Total Destroyed Aircraft	31.66%	15.58%	22.87%
F/A Flight Hours vs. Total Flight Hours	31.30%	30.13%	30.82%

***Air Force: A-7, A-10, F-15, F-16, F-117

***Navy/Marine Corps: A-4, A-6E, AV-8B, EA-6B, F-5E, F-14, F/A-18

The consequences of CFIT and MIDAIR mishaps are almost invariably destroyed aircraft and about 53% as many fatalities as the number of aircraft lost. The fatality rate is much higher in CFIT mishaps than it is in MIDAIR mishaps. For example, for FY92-04, 161 aircraft were destroyed and 86 pilot fatalities occurred in Air Force and Navy/Marine F/A CFIT and MIDAIR mishaps (Attachments 2 and 3). Table 1 clearly demonstrates the magnitude of the problem with about 28% of all USAF/USN/USMC F/A pilot fatalities and 23% of all their destroyed aircraft attributable to CFIT and MIDAIR mishaps, as well as more than $3B in lost aircraft assets. Later in this study, we will analyze the costs and benefits of Auto-CASs in F-16, F/A-18, F/A-22, and F-35 aircraft, and demonstrate that scores of lives would be saved and billions of dollars would be preserved.

B. COMMON MISPERCEPTIONS REGARDING CFIT AND MIDAIR MISHAPS

There are three common misperceptions that are frequently used to argue against installing Auto-CAS in F/A aircraft. The first is that only young, inexperienced pilots are involved in CFIT and MIDAIR mishaps. The second misperception is that recent flying experience is an important indicator of likelihood of being involved in a CFIT or MIDAIR mishap and the third is that by not flying at low altitudes the CFIT mishap rate will go down dramatically. The actual data on these mishaps would indicate otherwise. A detailed and statistically rigorous study entitled "Controlled Flight Into Terrain & Mid-air Collisions, Pilot Experience, Recency & Tactical Change" was recently completed by the Human Effectiveness Directorate, Air Force Research Laboratory (AFRL/HE). This study compared the recency and total flight experience of all USAF F/A pilots with the recency and total flight experience of USAF F/A pilots involved in both class A CFITs and mid-air collisions (MAC) to determine if there is any discernable predilection toward inexperience or lack of recency. The study also compared the CFIT rates of F-16 pilots before and after the cessation of low altitude weapon delivery training to determine if stopping that training had a significant effect on Class A CFIT mishaps in the F-16 fleet. The study concluded "Increasing 90-day recency, total time, or the cessation of the use of iron bombs in the F-16 has had no effect on USAF F/A class A CFIT rates. Increasing 90-day recency or total time had no effect on USAF F/A MAC rates." The abstract of this study appears in Attachment 4.

The results of the AFRL/HE study regarding currency reinforces and validates the findings of a report entitled "Epidemiology of USAF Spatial Disorientation Aircraft Accidents, 1 Jan 1958-31 Dec 1968", Barnum and Bonner, Aerospace Medicine, August 1971(Reference 3). The report states, "In our study, there was no evidence that individuals who had flown very few hours in the 90 days preceding their accident were any more likely to become spatially disoriented than individuals who had flown the normally expected number, or more, of hours."

None of the perceptions against installation of Auto-CAS have ever been validated by statistical study. In fact studies indicate the arguments against Auto-CAS are baseless.

C. Auto-CAS IS MILITARY CAPABILITY

Safety equipment is often perceived as a competitor for funding which adds no combat capability and therefore, when money is tight, it is often ranked below the funding line. This approach usually ranks aircraft, bombs, bullets, etc. ahead of survival equipment and ignores the potential preservation and enhancement of military capability that these systems can provide. Military capability is defined in Joint Chiefs of Staff Publication 1 as the "ability to achieve a specified wartime objective (win a war or battle, destroy a target set). It includes four major components: force structure, modernization, readiness and sustainability."

Auto-CAS preserves force structure by reducing attrition of pilots and aircraft. DoD can either buy excess capability (pilots and aircraft) to account for CFIT and MIDAIR attrition or conserve your assets by prevention of these mishaps. For the humans involved the latter approach is preferred.

Auto-CAS modernizes forces and allows more realistic training in the interdiction, close air support and air superiority missions. Auto-CAS provides a new capability to fully exploit the low altitude environment and engage in potentially disorienting conditions with safety. It also permits training of pilots for operations in the low altitude environment with less investment of time and resources at reduced risk. Another new capability provided by Auto-CAS is automatic deconfliction of manned and unmanned aerial vehicles operating in the same airspace.

Auto-CAS improves readiness and sustainability by reducing attrition due to preventable mishaps. Fewer replacement pilots need to be trained and replacement aircraft acquired thus allowing a unit to continue to fight for a longer period before requiring re-supply.

D. CFIT AND MIDAIR MITIGATION

To identify current CFIT and MIDAIR mitigation options, there are three areas to examine: policy, training, and technology. The STWG will not make recommendations to change policy or training because they are outside the scope of this study. The STWG will only look at technology solutions and the policies that affect them.

There are policy precedents for requiring collision avoidance system technology in passenger/cargo aircraft, by the FAA, the USAF, and the U.S. Navy.

FAA Final Rule [4910-13] requires a Terrain Awareness and Warning System (TAWS) be installed on turbine-engine aircraft configured for 6 passengers or more by 29 March 2005. A description of TAWS follows shortly.

Following the CT-43 crash in Croatia in April 1996 in which Secretary of Commerce Ronald H. Brown died, a USAF/XO Memorandum in March 1997 was issued on implementation of the AF

Navigation and Safety Master Plan. This memorandum directed all passenger and troop carrying aircraft to have a TAWS by FY2005.

The Naval Aviation Policy on Aircraft Safety Systems Avionics (9 November 1999) stipulates the CNO policy for acquisition and installation of both Ground Proximity Warning System (GPWS) and CAS safety systems on naval aircraft. The Navy's GPWS Operational Requirements Document (ORD, Serial #555-88-00, dated 5 May 2000) governs the continuing direction of GPWS integration in Navy/Marine Corps aircraft, as well as the evolutionary insertion of advanced technologies (including auto recovery systems) that expand or enhance protection against CFIT. To date, GPWS has been installed on over 1,500 Navy/Marine Corps aircraft, including the F/A-18 and AV-8B, and tailoring is underway for the EA-6B.

The Secretary of Defense issued a memorandum in July 2003 challenging the Services for a 50% reduction in preventable aviation accidents. This report clearly demonstrates that an acquisition policy directing all F/A aircraft, now and in the future to have an Auto-CAS would go a long way toward achieving that reduction in <u>preventable</u> aviation mishaps.

Additional support for acquisition of Auto-CAS comes from the Aerospace Medical Association (AsMA), the internationally recognized authority in aerospace medicine. As recently as 10 May 2005, AsMA passed the following resolution, which is now being considered for adoption by the American Medical Association.

AEROSPACE MEDICAL ASSOCIATION
RESOLUTION 05-01

PREVENTION OF CONTROLLED FLIGHT INTO TERRAIN (CFIT) MISHAPS IN AIRCRAFT WITH ELECTRONIC FLIGHT CONTROLS

THEREFORE BE IT RESOLVED: That all aircraft with digital electronic flight controls should incorporate completely automated systems that prevent collision with the ground.

The AsMA passed this resolution following a year of intensive study. AsMA concluded that significant numbers of lives could be saved by requiring aircraft with digital flight control technology to incorporate automatic systems designed to prevent CFIT. The AsMA consists of aviation and aerospace medicine physicians, pilots, engineers, nurses, military officers, technicians, airline medical directors, members of national aviation regulatory bodies (such as the FAA and JAA) from over eighty countries. The overwhelming majority vote of more than 95% of the Association members in attendance for adopting this resolution reflects a high degree of agreement with this point of view. This resolution has generated both interest and support from the US Senate. In addition, it led HQ USAF XOR to comment that the Air Force plans to install Auto-GCAS on both the F/A-22 and the F-35.

When we look at current technology there are a plethora of options. In many mishaps where no definitive cause is found, the need for advanced information systems on aircraft is highlighted. These systems would provide critical data after a mishap to determine causes and enable proactive prevention programs like the Military Flight Operations Quality Assurance (MFOQA)

program. MFOQA will bring real benefits to the AF and Navy standardization and evaluation (STAN/EVAL, NATOPS) programs, allowing trend analysis and earlier discovery of potential problems but it is just now getting started and it will not prevent most CFIT and MIDAIR mishaps.

Another area where technology might help is in fielding spatial disorientation trainers and research into sensory support systems like the tactile vest. These systems are still experimental and have never been shown to offer any mishap prevention value.

The most useful technologies for CFIT prevention deployed to date have been terrain warning systems. The commercial sector has been developing ground proximity warning systems (GPWS) for over 40 years and, as mentioned above, the FAA now requires TAWS on all turbine powered aircraft carrying six passengers or more. Civil aviation has yet to see a CFIT involving an aircraft equipped with the 4th generation GPWS known as the Terrain Awareness and Warning System (TAWS). Because the commercial sector's flight regimes are much less dynamic compared to military tactical aircraft, the military has developed its own tactical ground collision warning and avoidance systems which are optimized for F/A operations.

Terrain avoidance systems have been under development by the DoD since the early 1950's. Early systems focused on altitude clearance and used radar and barometric altimeters to give clearance plane and descent after takeoff warnings. The next generation incorporated navigation information from radar, radio navigation, and inertial navigation systems to determine the three-dimensional position relative to the earth with ever increasing precision. TAWS uses the Global Positioning System (GPS) to update an inertial platform and provides three-dimensional position to within a few meters of the aircraft's actual position. Parallel in time with the development of accurate positioning systems has been the movement from maps and charts requiring pilot interpretation to electronic map displays generated from very detailed and accurate digital terrain databases. Combining the position information with the terrain database and some computing power provides a robust, predictive warning system of impending CFIT to the pilot. Examples of these systems have been tested and are now found in some F-16 and F/A-18 aircraft.

The Navy has been working for over 14 years on ground proximity and terrain awareness systems. These have evolved from the Ground Proximity Warning System (GPWS), which initially relied on a radar altimeter providing protection primarily over level terrain and water, into a Terrain Awareness Warning System (TAWS) utilizing GPWS, digital terrain data and GPS to provide a forward looking capability with warnings given about all terrain including mountains. The Navy GPWS and TAWS are back-up safety systems, providing directive cues to the pilot but relying on the pilot to fly the aircraft to safety. The GPWS was fielded on the F/A-18 in 1996 and on the AV-8B in 1997. Both aircraft have seen a downward trend in CFIT mishaps since the incorporation of GPWS (see Attachment 7). In addition, the F/A-18 has documented two "saves" attributed to the GPWS.

The Navy's TAWS compares the calculated height above terrain to a digital terrain elevation database and provides protection in all terrain environments, including rising terrain. The TAWS algorithm uses available aircraft information for protection computations, which are then fed into the platform computer that hosts TAWS. Warnings are sent to the pilot via the available

pilot-vehicle interfaces (PVI), e.g. heads-up-display, communication systems. The aural and visual warnings are directive to ensure the appropriate response to recover the aircraft (e.g., "pull-up", "power", "roll left", "roll right"). TAWS reached the field in F/A-18 aircraft in 2004. The Navy anticipates a further reduction in F/A-18 CFIT mishaps (not attributable to PHYSIO) due to the incorporation of TAWS. It should be noted that the Navy TAWS and the FAA TAWS are separate and distinct, parallel developments using similar approaches for terrain avoidance optimized for different types of operations (military tactical vs. commercial passenger).

The Air Force has been developing warning systems similar to the Navy's for 20 years and its latest system, deployed in the F-16, is called the Predictive Ground Collision Avoidance System (PGCAS). PGCAS functions by accurately establishing the aircraft's position relative to the surrounding terrain as mapped into the Digital Terrain System (DTS). DTS scans a corridor and develops a "worst case" two dimensional terrain-obstacle profile from the data in the corridor. Timely PGCAS advisories are provided for terrain and obstacles located within at least 10 seconds time of flight from the aircraft. The PGCAS algorithm provides inputs to the F-16 core avionics computers which will generate HUD, MFDS, and VMU advisories to the pilot when the aircraft trajectory penetrates the pilot-selectable Minimum Terrain Clearance (MTC) setting, obstacles included (Reference 4).

The Navy TAWS and the Air Force PGCAS are the most current warning systems deployed in F/A aircraft and they work well <u>if</u> the pilot takes the corrective actions they recommend in a timely manner. However, if the pilot is task saturated or has channellized attention, the pilot is at risk of not perceiving the warnings and failing to take corrective actions resulting in CFIT. Another difficulty with manual systems is excessive nuisance warning. This occurs because manual systems must warn pilots in time for them to act. Automatic recovery systems avoid this by recovering at the last possible moment (Reference 10). There were cases in the F-16 mishaps between FY92 and FY04 where the maneuvering began at medium altitudes and ended in a CFIT when the mishap pilot either ignored or did not perceive the warnings. Another reason that these warning systems are ineffective is that some pilots suffered GLOC or Hypoxia and were unable to perceive the warnings and recover the aircraft in time. There were 14 GLOC mishaps in the total of 87 CFIT mishaps (16.1%) found in the DoD historical study. Whatever the reason, it is clear that CFIT mishaps continue to happen with some regularity despite training programs and various warning systems that require active pilot inputs to avoid collisions.

Airborne Collision Avoidance Systems for civilian aircraft have been developed that use cooperating radar beacon transponders to provide traffic advisories and recommended escape maneuvers. The current version used by civil and some military cargo/passenger aircraft is the Traffic Alert and Collision Avoidance System II (TCAS II). It should be noted that TCAS provides no protection against aircraft that do not have an operating transponder. Additionally, it is dependent on the accuracy of the threat aircraft's reported Mode C altitude, and on the expectation that the threat aircraft will not make an abrupt maneuver that thwarts the TCAS escape maneuver. The FAA mandated TCAS II on all commercial air carriers in 1993 and then in 1995 extended the requirement to all turbine powered aircraft with passenger seating of more than 10 seats.

The Air Force is installing an Enhanced TCAS (ETCAS) on many of its passenger/cargo airplanes which provides an extended surveillance range and the capability to coordinate formation flying in addition to standard TCAS operations. TCAS II and ETCAS both use a Mode S transponder and a separate TCAS processor.

The Navy is pursuing a research and development program called Mid-Air Conflict Avoidance System (MCAS) to provide situational awareness for formation flying and deconfliction of flights in close proximity for Navy and Marine Corps tactical aircraft. MCAS uses Automatic Dependent Surveillance – Broadcast (ADS-B), 1090 Extended Squitter (ES) as the datalink. Information used (transmitted on 1090ES) is: aircraft ID, range, bearing, heading, and relative altitude, which are then presented on own ship displays. Aural and visual cues are provided to alert flight crews of potential threat aircraft. The MCAS is embedded in an existing Government Mode 5 IFF Transponder. The advantages of this approach are the improved security for the data link and the elimination of a separate collision avoidance processor box. This last feature is particularly important in F/A aircraft where adding an additional processor box usually entails a major engineering effort to shoe-horn it into an already crowded airframe. MCAS has been demonstrated by the Navy using an UH-1 and an Aerosky UAS.

TCAS II, ETCAS, and MCAS are all manual systems requiring pilot intervention to avoid the collision. MIDAIR collision avoidance is much more complicated than CFIT avoidance because the threat can come from all aspect angles and the closing rates can be very high particularly in the tactical aircraft environment. Just as in the Ground Collision Avoidance Systems above, the human operator is now the limiting factor in reliably avoiding a mishap.

III. THE TECHNOLOGICAL FUTURE

A. CFIT MITIGATION

Because CFIT mishaps continue despite significant investments in training and warning systems, the DoD needs to take the next step and field a system that not only warns the pilot but also takes control, if necessary, to fly the aircraft out of danger and then return control to the pilot. Practical implementation of this system would be easiest in a "Fly-by-Wire" aircraft where the flight control system is a digital computer control system such as in the F-16, F/A-18, F/A-22, and F-35. An important point is that the main component of the system would be software.

Such a system has been developed and tested over a period of 20 years on the F-16 and is considered a "mature technology" by the Air Force Materiel Command (AFMC) (Reference 2). The system, called the Automatic Ground Collision Avoidance System (Auto-GCAS), calculates aircraft trajectory with respect to terrain so that it can initiate automatic recovery to avoid terrain impact. Recovery occurs when a 5 G escape maneuver would be needed to avoid ground impact. The system visually warns pilots prior to removing them from control, with the length of warning dependent on the trajectory. Auto-GCAS delivers an aural cue indicating the pilot is no longer in control of the aircraft, rolls the aircraft level and upright, and pulls away from the ground. The system is designed to recover regardless of aircraft attitude. Auto-GCAS in its current configuration is not effective if the aircraft has departed controlled flight or the landing gear is extended. The system could and should be modified to provide collision avoidance when the gear is extended since some CFIT mishaps do occur in the landing configuration.

A common objection to Auto-GCAS among people who have **<u>not</u>** actually flown the system is that it lessens mission capability because of early or "nuisance" recovery maneuvers. As a part of testing, nuisance boundaries were defined below which a recovery maneuver should be initiated and above which any system initiated recovery would be a nuisance. In at least one test run the test pilot initiated recovery before the system because it was "out of his comfort zone". In another, the pilot thought he was recovering the aircraft but the Auto-GCAS system was actually ahead of him and prevented him from hitting the ground saving his life. In this case, the pilot did not realize that the system had activated until the data was downloaded from the aircraft. According to the test report (Reference 5), "The system provided excellent ground clearance for all mishap profiles that were replicated. At the same time, the **<u>Auto-GCAS was nuisance free</u>** for all tested medium- and high-altitude operations. For operations at and above 500 feet AGL, the Auto-GCAS was satisfactory without modification. However, there were some minor mission impacts when aggressive low-level maneuvers were performed below 500 feet over very rough terrain, and below 125 feet over smooth terrain. ...... Design modifications ... identified in this report ... are expected to eliminate these areas of minor mission impact." The report also states "<u>The F-16 could be utilized at very low altitudes while at the same time seeing a dramatic reduction in mishap rates if equipped with Auto-GCAS.</u> The results from these tests combined with previous AFTI/F-16 Auto-GCAS testing validated the process by which the design was applied to an air vehicle. Therefore, given the extreme environment under which these tests were conducted, it is reasonable to expect satisfactory results to be achieved on other vehicles."

The Navy's concept of operations for an automatic ground collision avoidance system (similar to Auto-GCAS) on the F/A-18 is that TAWS will remain as a back-up safety system providing aural and visual cues to the aircrew of impending CFIT and that Auto Recovery will be an extension of TAWS capability, providing aircraft flight path information to the flight control computer. Auto Recovery will engage if the pilot fails to respond or fails to respond adequately to a TAWS warning in time to recover the aircraft.

In summary, automatic ground collision avoidance systems are readily achievable technologies that can save lives, preserve, and improve combat capability of F-16, F/A-18, F/A-22 and F-35 aircraft.

B. MIDAIR MITIGATION

The technological approaches to increased reduction of the MIDAIR mishap rate by incorporating an automated system are not as mature as those for CFIT mitigation. The only one that has been tested is the Automatic Air Collision Avoidance System (Auto-ACAS), whose program concept was developed by a joint AFRL/VA-ASC/EN IPT. The Auto-ACAS builds on the Auto-GCAS approach but is more complicated because of the presence of multiple moving platforms. Auto-ACAS automatically prevents penetration of a minimum clearance distance ("bubble of protection") from other aircraft by evaluating escape trajectories against neighboring aircraft, warning the pilot of impending collision, and automatically executing an evasion maneuver if the pilot takes no action. The Air Vehicles Directorate (AFRL/VA) successfully

tested the Auto-ACAS in two F-16 flight sessions held at Edwards Air Force Base, California in 2003. The Auto-ACAS system used the Situational Awareness Data Link (SADL) data to determine if a collision was imminent and, if so, temporarily took control of the aircraft away from the pilot for a very short time to steer each aircraft into an optimal escape maneuver. As soon as the aircraft began to diverge, the system returned control to the pilot.

The tests provided proof of concept of collision avoidance for head-on, maneuvering, and multi-ship flights with cooperating aircraft. While much work remains including finishing nuisance evaluation, integration with Auto-GCAS, extending capability to non-cooperating aircraft, and operating with UAVs, Auto-ACAS is the most promising means of F/A MIDAIR prevention developed to date.

C. INTEGRATION OF Auto-GCAS AND Auto-ACAS

The provision of separate ground collision and airborne collision avoidance systems in passenger and cargo aircraft is quite reasonable given their relatively benign maneuvering. In contrast, the F/A mission often requires violent maneuvering at high speeds at both high and low altitudes with multiple aircraft (enemy and friendly). The collision threat is just as likely to be the terrain and obstacles as other aircraft. In such a dynamic environment the F/A aircraft needs an integrated automatic collision avoidance system (Auto-CAS) that integrates both the Auto-GCAS and Auto-ACAS functions into a single system. Given the relative technical maturity of the two functions it would be quite reasonable for F/A Auto-CASs to incorporate the Auto-GCAS function first into a flight control system that has been designed from the beginning to accommodate both automatic ground and airborne collision functions. The Auto-ACAS algorithms could then be added when they are mature enough for operational use.

IV. COST-BENEFIT ANALYSIS

Automatic Collision Avoidance Systems hold great promise for significant preservation of lives, aircraft, dollars, and combat capability. This section presents some projections of the benefits Auto-CAS will bring and then gives some preliminary estimates of Auto-CAS costs.

A. Auto-CAS BENEFITS

The projection of benefits uses a simple methodology of multiplying the historical mishap rates found in Attachments 5 and 6 by the estimated remaining fleet hours for each aircraft to estimate the numbers of lives, aircraft, and dollars saved.

The important assumptions in this projection are:
<u>System:</u>
Auto-GCAS is 98% effective against CFIT

Auto-ACAS is 75% effective against MIDAIR
Navy TAWS with Auto Recovery is 80% effective against CFIT

Note: The Air Force Auto-GCAS is assumed to be 98% effective against CFIT based on their experience in flight testing Auto-GCAS and a detailed analysis of 48 USAF F/A CFIT mishaps. The Navy's Auto Recovery is assumed to be a more conservative 80% due to their lack of experience in automatic recovery systems. Auto-ACAS is deemed only 75% effective because its data link capabilities limit its ability to prevent low aspect angle collisions from fingertip formation. This assessment is based upon a detailed analysis of 30 USAF F/A MIDAIR mishaps over a 13 year period. Development of a lightweight external sensor system will be required to achieve protection from low aspect angle collisions and raise the degree of MAC protection from 75% to close to 100%.

Costs:
Replacement cost of F-16 is $35M/aircraft
Replacement cost of F/A-22 is $120M/aircraft
Replacement cost of F-35 (Air Force) is $38.1M/aircraft
Replacement cost of F/A-18A+ - F is $80.8M/aircraft
Replacement cost of F/A-18G is $67.1M/aircraft

Mishap Rates:
F/A-22 mishap rates are a blend of F-15 (80%) and F-16 (20%) historical rates
F-35 (Air Force) mishap rates are a blend of F-16 (90%) and A-7 + A-10 (10%) historical rates
F/A-18 mishap rates take into account phase in of Navy TAWS on F/A-18 aircraft

It should be noted that other blends of the historical rates for the F/A-22 and F-35 could be calculated to reflect more or less time spent in fighter or attack missions.

F-16 Benefits
Estimated benefits for implementation of Auto-CAS in the F-16 are based on beginning installation in FY11 and completing in FY12. The remaining fleet hours estimates were calculated by AFRL/HE using system program office (SPO) estimates for service life of current F-16s and their historical utilization hours. Projected benefits for the F-16 appear in Table 2 and complete details for them can be found in Attachment 5.

Table 2
F-16 Auto-CAS Benefit Analysis

F-16 Projections FY 11-25	CFIT	MIDAIR	CFIT + MIDAIR
Total Class A Mishaps Prevented	15.3	7.2	22.5
Total Pilots Saved	10.8	2.1	12.8
Total Fatalities Saved	11.2	10.7	21.9
Total Aircraft Saved	17.1	8.6	25.7
Total Mishap Costs Saved	$614,690,761	$309,491,798	$924,182,560

F/A-22 Benefits

Estimated benefits for implementation of Auto-CAS in the F/A-22 are based on beginning installation in FY11 and completing in FY12. The remaining fleet hours estimates were calculated by AFRL/HE using SPO estimates for service life of F/A-22s and their projected utilization rates. Projected benefits for the F/A-22 appear in Table 3 and complete details for them can be found in Attachment 5.

Table 3
F/A-22 Auto-CAS Benefit Analysis

F/A-22	**BLEND 80% F-15 / 20% F-16**		
Projections FY 11-35	**CFIT**	**MIDAIR**	**CFIT + MIDAIR**
Total Class A CFIT or MIDAIR Mishaps Prevented	6.1	4.2	10.3
Total Pilots Saved	5.4	1.2	6.6
Total Fatalities Saved	5.5	3.3	8.8
Total Aircraft Saved	7.0	5.9	12.9
Total Mishap Costs Saved	$862,687,840	$734,761,286	$1,597,449,125

F-35 (Air Force Variant)

Estimated benefits for implementation of Auto-CAS in the F-35 are based on beginning installation in FY11 and completing in FY13. The remaining fleet hours estimates were calculated by AFRL/HE using joint program office (JPO) estimates for service life of AF F-35s and their projected utilization rates. Projected benefits for the F-35 appear in Table 4 and complete details for them can be found in Attachment 5.

Table 4
F-35 (Air Force Variant) Auto-CAS Benefit Analysis

F-35 - Air Force	**BLEND 90% F-16-/-10% A-7+A-10**		
Projections FY 11-35	**CFIT**	**MIDAIR**	**CFIT + MIDAIR**
Total Class A CFIT or MIDAIR Mishaps Prevented	61.3	28.2	89.5
Total Pilots Saved	43.3	8.2	51.5
Total Fatalities Saved	45.0	41.2	86.2
Total Aircraft Saved	68.2	33.9	102.1
Total Mishap Costs Saved	$2,734,903,143	$1,358,123,050	$4,093,026,193

F/A-18

Estimated benefits for implementation of an Auto Recovery TAWS in the F/A-18 are based on software installation in FY15. The F/A-18 Program Manager Air (PMA) provided the remaining flight hours from FY08 through FY32. The F/A-18 Auto Recovery solution presented here will only provide CFIT avoidance. (The Navy has no automatic MIDAIR collision avoidance system

in development, and will leverage off the Air Force's work.) Due to the fact that GPWS has been successfully fielded in the F/A-18 since 1996 and TAWS is currently being fielded, the added benefits of an automatic recovery system are primarily in protecting against CFITs caused by PHYSIO coded mishaps. Projected benefits for the F/A-18 are presented in Table 5 and complete details can be found in Attachment 6.

Table 5
F/A-18 Auto Recovery Benefit Analysis

Projections FY08-32	CFIT	PHYSIO	TOTAL
Total Class A Mishaps Prevented	1.7	6.3	8.0
Total Pilots Saved	1.6	4.2	5.8
Total Fatalities Saved	1.7	4.2	5.9
Total Aircraft Saved	1.7	6.3	8.0
Total Mishap Costs Saved[5]	$137,452,178	$507,515,734	$644,967,912

B. Auto-CAS COSTS

This section will attempt to estimate the costs associated with fielding Automatic Collision Avoidance Systems in F-16, F/A-18, F/A-22, and F-35 aircraft. The Auto-CAS benefits calculations of the preceding section were based on historical records and replacement costs both of which are fairly well defined and there is little uncertainty associated with them. In contrast, estimates of costs to field new technologies with little or no historical background are much more uncertain and should be considered as rough order-of-magnitude projections. Recognizing this problem, the STWG has consulted numerous safety, SPO, PMA, test and evaluation, and industry experts and believes that the following projections are reasonable given current knowledge. All costs are independent estimates for each aircraft **not** taking into consideration any synergy between programs that can be obtained by the risk reduction program mentioned below.

The proposed Air Force approach would be to use the F-16 as a stepping-stone to other DoD platforms. Since Auto-GCAS has been extensively tested and is considered a mature technology; fielding it in some F-16s would be the quickest way to a flying demonstrator, would provide significant risk reduction for incorporation into the F-35 and F/A-22, and provide leave-behind capability for the F-16 fleet. Additionally, performance of Joint Service evaluations would be the best route to solid requirements definition for other platforms and could get user and command buy in. The estimated costs for this phased approach using an F-16 as a test bed are $20.9M for Auto-GCAS and $28.6M for Auto-ACAS spread over the fiscal years 2006 to 2010.

In addition, a presentation was given to SECAF in August 2000 in which the F-16 SPO estimated $500M to equip the entire F-16 fleet with Auto-GCAS including new flight control computers with installation in FY06-FY10 (Reference 6). Adjusting that 2000 estimate for inflation by multiplying by 1.12 (Reference 7) and deducting $49.5M for the F-16 test bed work

on both Auto-GCAS and Auto-ACAS gives a cost of $510.5M to add Auto-CAS to the F-16 fleet. In fact, obsolescence of current F-16 flight computer components may drive a change to a new F-16 flight computer. Since a significant percentage of the originally estimated cost was due to the need for a new computer with a higher throughput, the incremental cost of putting Auto-GCAS on the F-16 may be significantly lowered if the computer will be purchased anyway to keep the fleet airworthy.

Implementation of Auto-GCAS and Auto-ACAS in the F/A-22 was estimated in a presentation to the ASI TF in 2004 (Reference 8) as costing $260M. That estimate assumed starting funding in FY06 with installation beginning in FY10 and completing in FY13. The estimate was re-confirmed by the F/A-22 SPO in August, 2005.

The estimate for implementation of Auto-GCAS and Auto-ACAS in the F-35 used in this study is $206M. This number was derived from the F/A-22 estimate above by deleting the retrofit costs. The reason for this approach is that while the F-35 is being fielded later and its cost data are more uncertain, both aircraft will have very similar fly-by-wire flight control systems designed by Lockheed Martin. Additionally a recent draft report of the Lockheed-Martin Joint Strike Fighter Team titled, "Study to Determine the Feasibility of Implementing an Automatic Air Collision Avoidance System on the F-35 Joint Strike Fighter" noted that current flight control computational capability is more than adequate to host Auto-CAS systems without additional investment in hardware (Reference 9). Since Auto-CAS implementation in the F-35 will be a software installation only, the retrofit costs in the F/A-22 estimate which were for hardware upgrades have been dropped in the F-35 estimate.

The Navy estimate for equipping the F/A-18 TAWS with Auto Recovery is $91.8M for research, development, testing, evaluation, and software update from FY08-FY14. Software fleet release would occur in FY15.

Comparison of the costs cited above with the dollars saved from Tables 2 through 5 results in the rough order-of-magnitude savings found in Table 6.

Table 6
Auto-CAS Cost Benefit Analysis

F-16	
Total Mishap Costs Saved	$924.2M
Estimated Cost	$510.5M
Dollar Savings	$413.7M
F/A-18	
Total Mishap Costs Saved	$645.0M
Estimated Cost	$91.8M
Dollar Savings	$553.2M
F/A-22	
Total Mishap Costs Saved	$1,597.4M
Estimated Cost	$260.0M
Dollar Savings	$1,337.4M
F-35 USAF	
Total Mishap Costs Saved	$4,093.0M
Estimated Cost	$206.0M
Dollar Savings	$3,887.0M

In summary, if completely implemented on the four fighter/attack aircraft, Auto-CAS could save approximately 78 pilots, 150 aircraft ($7.3B in aircraft assets) while corresponding implementation costs are estimated as 1.07 billon dollars. The resulting overall return on investment is about 6.8 to 1.

Looking at each of the four aircraft we find the return on investments to be: F-16—1.8 to 1, F/A-18—7.0 to 1, F/A-22—6.1 to 1, F-35 (USAF)—19 to 1.

If Auto-CAS is not implemented on these four aircraft, the losses to CFIT and MIDAIR mishaps will roughly average 4 pilots, 7 aircraft and 330 million dollars a year for the F/A community.

These numbers argue very strongly for fielding Auto-CAS in all F/A-22 and F-35 aircraft and in at least later models of F-16 and F/A-18 aircraft.

V. RECOMMENDATIONS

Very large losses in lives, aircraft, and dollars due to CFIT and MIDAIR mishaps continue in the DOD fighter/attack community despite our best efforts at mitigation by training and fielding collision avoidance warning systems. Improvements in CFIT and MIDAIR mishap rate reduction by improving training or current warning systems will be minimal at best. The only

demonstrated technologies that can make an "order of magnitude advance" in saving lives and aircraft are those Automatic Collision Avoidance Systems such as Auto-GCAS and Auto-ACAS.

Given the large savings that Auto-CAS promise, The STWG recommends that a Joint Auto-CAS program be established that would:

a) Initiate a risk reduction program to refine the requirements for, and integrate, Auto-CAS into F/A aircraft.

b) Establish overarching and top-level functional requirements for automatic collision avoidance systems.

c) Direct the services to integrate Auto-CAS capabilities in F/A-22, F-35, F-16, and F/A-18 aircraft leveraging Auto-GCAS, US Navy TAWS, Auto-ACAS, and other civil and military CAS development efforts.

d) Continue integrating manual systems into platforms where automated systems are not practical.

VI. REFERENCES

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9. Draft Report "Study to Determine the Feasibility of Implementing an Automatic Air-Collision Avoidance System (ACAS) on the F-35 Joint Strike Fighter", 27 May 2005.

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ATTACHMENT 1, AVIATION MISHAPS DEFINITIONS

AVIATION	CODE	DEFINITION	INCLUDES	EXCLUDES
ABRUPT MANEUVER	AMAN	Damage or injury caused by intentional abrupt maneuvering.	Structural damage from aerodynamic overstress (e.g., over-g). Damage or injury when objects or people are thrown about by abrupt maneuvering.	All midair collisions (see MIDAIR). Collisions with terrain, water, trees and man-made obstacles (see CFIT). Hard landings, skids and runway excursions (see AFOPS).
AIRFIELD OPERATIONS	AFOPS	Mishaps occurring during takeoff, landing or other powered movement on prepared airfield surfaces, austere fields and helicopter landing zones.	Collisions with aircraft, UAV, flightline vehicles or equipment, or stationary objects (e.g. light poles) while moving on the ground or in hover taxi. Wing, tail or nacelle scrapes. Skids, hydroplaning, departures from prepared surfaces, and runway excur	Towing mishaps (see GHAND). Intentional gear-up landings, runway excursions and other mishaps when primarily caused by system or powerplant failures (see SYSTEM and POWER). Wildlife strikes or wildlife activity (see BASH). Aircraft/UAV touchdown prior to available runway underrun (see CFIT).
CABIN & CARGO	CAB/CAR	Miscellaneous occurrences in either the flight deck, passenger cabin or cargo compartment.	Mishaps when there are cargo or equipment leaks (e.g., fuel from cargo, over-serviced lavatories) or cargo shifts.	Smoke & fumes from overheated or failed electrical and mechanical components (see SYSTEM).
CONTROLLED FLIGHT INTO TERRAIN	CFIT	Collision with terrain, water, trees or a man-made obstacle during flight prior to planned touchdown.	Mishaps involving impact with terrain, water, trees or man-made obstacles where the aircraft/UAV is controllable, and the pilot is actively controlling the aircraft/UAV or the pilot's ability to control the aircraft/UAV is reduced to due to spatial disorientation. Mishaps where the aircraft/UAV is flown in controlled flight to a point where it is no longer possible to avoid unintended ground impact (e.g. attempted maneuver with insufficient altitude or airspeed, low altitude overbank or flight into a box canyon), regardless of subsequent pilot reaction (e.g. ejection, stall, spin, etc.).	Hard landings near the intended runway (e.g., on the underrun) or landing zone (see AFOPS). Aircraft departures from controlled flight that ultimately result in ground impact when collision avoidance was still reasonably preventable prior to departure (see PLOCI). Unavoidable ground impact due to system failure or malfunction (e.g. flight control failure, loss of thrust)(see SYSTEM and POWER). Mishaps resulting from encounters with whiteout or brownout conditions (see WOBO). Mishaps resulting from insufficient power (see IPOWER).

AVIATION MISHAP TYPES	CODE	DEFINITION	INCLUDES	EXCLUDES
ENVIRONMENT/ WEATHER	ENV/WX	Mishaps resulting from encounters with weather or man-made environmental phenomena.	Weather (e.g., lightning, static discharge, thunderstorms, hail, freezing rain, ice accumulation, wind shear, turbulence, mountain waves, volcanic ash, etc.) and man-made environmental phenomena (e.g., wake turbulence and vortex encounters).	Carburetor icing (see FUEL). Mishaps resulting from encounters with whiteout or brownout conditions (see WOBO).
EXTERNAL OPERATIONS	EXT OPS	Mishaps related to personnel or equipment physically attached but external to the aircraft.	Rappelling, fast-rope (specialized rappelling), stabo (stabilized extraction w/o lift), rescue hoist operations, and sling-loads.	Injury to personnel or damage to aircraft caused by the malfunction or failure of fuselage or wing stores (e.g., bombs, missiles, external tanks, pods, etc.) or their attachment hardware (see SYSTEM).
FIRE/EXPLOSION	FIRE/EXP	Mishaps initiated by an external source of fire or explosion.	Mishaps resulting from an external fire (e.g., forest fire, grass fire, etc.) or explosion (e.g., unidentified weapons cache, rocket arming and exploding early, etc.).	Fire and explosions initiated by aircraft/UAV system or powerplant failure (see SYSTEM and POWER) or where a fire/explosion is secondary to the principle cause.
FOREIGN OBJECT DAMAGE	FOD	Damage due to foreign objects or debris from another failed aircraft/UAV component.	Mishaps where aircraft/UAV damage is due a foreign object or impact with another failed component (e.g., shards of tires). Mishaps where powerplant damage is due to an ingested object (e.g., ice, support equipment, hand tool, runway and taxiway debris, fasteners, panels, shards from failed tires, etc.	Damage from wildlife strikes and wildlife activity (see BASH). Powerplant damage due to the failure of internal powerplant components (see POWER).
FUEL-RELATED	FUEL	One or more powerplants experienced reduced or no power output due to a fuel anomaly.	Fuel exhaustion, starvation, mismanagement, contamination, trapped fuel, the wrong fuel, lack of required additives, carburetor icing and the inadvertent placement of a throttle to cutoff.	Powerplant initiated fuel problems (e.g., fuel controls) (See POWER).

AVIATION MISHAP TYPES	CODE	DEFINITION	INCLUDES	EXCLUDES
GROUND HANDLING & SERVICING OPERATIONS	GHAND	Mishaps resulting from improper ground handling or servicing or as the result of the failure of ground handling or servicing equipment.	Towing and cargo loading/unloading events. Ground servicing mishaps (e.g., jacking, craning, refueling, deicing, etc). Damage to other objects due to jet blast from stationary aircraft/UAV.	Damage to an aircraft/UAV (e.g., powerplants, systems) undergoing ground operational checks (see POWER and SYSTEM). Ground Handling and Servicing Operations mishaps that occur onboard ships (see SHIP).
INSUFFICIENT POWER	IPOWER	Mishaps resulting in ground or water impact when power required exceeds power available.	Mishaps involving helicopters, tilt-rotors and vertical takeoff and landing aircraft/UAV where power required is greater than power available, settling with power, and rotor droop/loss of tail rotor authority when caused by requesting more power than is available.	All mishaps involving conventional takeoff & landing aircraft/UAV. All mishaps to vertical takeoff & landing aircraft/UAV when flown conventionally. Mishaps involving helicopters, tilt-rotors and vertical takeoff & landing aircraft/UAV that occur due to insufficient power when that insufficiency is caused by a powerplant failure (see POWER).
MIDAIR COLLISION	MIDAIR	Collision between aircraft or UAV when intent for flight exists.	Mishaps resulting from collision between aircraft/UAV when intent for flight exists. Includes inadvertent contact during formation takeoffs and air-refueling operations.	Mishaps resulting from collision between aircraft or UAV when intent for flight does not exist (see AFOPS).
PHYSIOLOGICAL	PHYSIO	Injury, illness or abnormal symptoms experienced by aircrew or others as a result of the dynamic flight environment.	Spatial disorientation that does not result in a midair collision or controlled flight into terrain. All G-induced loss of consciousness, hypoxia and other physiological events.	Spatial disorientation events occurring during whiteout/brownout conditions or resulting in a midair collision or controlled flight into terrain (see WOBO, MIDAIR and CFIT).

AVIATION MISHAP TYPES	CODE	DEFINITION	INCLUDES	EXCLUDES
PILOT LOSS OF CONTROL IN-FLIGHT	PLOCI	Aircrew failure to maintain control of the aircraft or UAV while in flight.	Mishaps resulting from failure to control the aircraft/UAV during flight, when that loss of control is not primarily related to environment, weather or any system failure. Includes departures, stalls and spins. For UAVs, includes "lost link" mishaps whe	Control loss due to a powerplant or system failure/malfunction (see POWER and SYSTEM). Control loss due to environment/weather (see ENV/WX). Helicopter, tilt-rotor and vertical takeoff and landing aircraft/UAV mishaps resulting from encounters with whiteout or brownout conditions (see WOBO). Helicopter, tilt-rotor and vertical takeoff and landing aircraft/UAV mishaps resulting from insufficient power (see IPOWER).
POWERPLANT FAILURE OR MALFUNCTION	POWER	Failure or malfunction of a thrust-producing system or related components.	Mishaps resulting from failure or malfunction of an aircraft/UAV thrust-producing system or related component (e.g., fuel controls, engine-mounted gearboxes, propellers, thrust reversers, thrust vectoring components). Includes maintenance and crew induced failures	Damage due to ingestion of foreign objects and debris (see FOD). Damage from wildlife strikes (see BASH). Damage to gearboxes that are not engine-mounted (e.g., aircraft mounted accessory drives) (see SYSTEM).
SHIP-RELATED	SHIP	Mishaps resulting from ship-board flight or ground operations or the failure of unique ship-board equipment for launching, maintaining or recovering aircraft/UAVs.	Mishaps which are a result of flight or ground operations onboard any ship (e.g., ramp strikes, aircraft/UAV movement, cargo loading/unloading events, refueling, etc.) or the failure of unique ship-board equipment (e.g., parted wires, catapult failures, etc.	Events that do not physically involve the shipboard environment, such as flights originating from a ship but not in direct contact with the ship. Events that could equally have occurred in a non-ship board environment (e.g., powerplant or system failure,
SYSTEM FAILURE OR MALFUNCTION (NON-POWERPLANT)	SYSTEM	Failure or malfunction of a system or component - other than the powerplant.	Mishaps resulting from failure of aircraft/UAV system or component - other than the powerplant. Includes maintenance and crew induced failures.	Damage from wildlife strikes and wildlife activity (see BASH). Failure of low dollar value components (e.g., fasteners, sealant, fairings, panels, tires, etc.) that result in significant foreign object damage to aircraft/UAV or powerplants (see FOD).

AVIATION MISHAP TYPES	CODE	DEFINITION	INCLUDES	EXCLUDES
WHITEOUT/BROWNOUT	WOBO	Mishaps resulting from encounters with whiteout or brownout conditions during takeoff or landing.	Mishaps involving helicopters, tilt-rotors and vertical takeoff & landing aircraft/UAV resulting from encounters with whiteout or brownout conditions during takeoff or landing.	All mishaps involving conventional takeoff & landing aircraft/UAV. All mishaps to vertical takeoff & landing aircraft/UAV when flown conventionally. Mishaps involving helicopters, tilt-rotors and vertical takeoff & landing aircraft/UAV where whiteout or brownout conditions are present but the mishap results from other conditions such as powerplant failure, system failure, or rotor droop (see POWER, SYSTEM and IPOWER).
WILDLIFE STRIKE	BASH	Damage due to collisions with wildlife or resulting from wildlife activity.	Collisions with birds and other wildlife. Damage resulting from wildlife activity such as nesting within aircraft/UAV.	
OTHER	OTHER	Any occurrence not covered under another category.	Used when insufficient information exists to categorize the occurrence (unknown and undetermined). Also used for mishaps that occur infrequently such as friendly fire and aerodrome issues (e.g., design, services and functionality).	

ATTACHMENT 2, USAF F/A HISTORICAL DATA

Fighter/Attack CFIT Mishap Summary FY 92-04						
	A-7	A-10	F-15	F-16	F-117	ALL
Total Class A Mishaps[1]	3	29	52	155	7	246
Total CFIT[2,3] Mishaps	2	12	5	34	1	54
CFIT AF Pilot Fatalities	2	8	6	24	1	41
CFIT Other Fatalities	0	0	0	1	0	1
Number CFIT Destroyed Aircraft	2	12	6	38	1	59
Total CFIT Mishap Cost[4]	$8,752,924	$111,598,444	$175,998,694	$687,788,134	$51,426,055	$1,035,564,251
Total Flying Hours[1]	34,392	1,595,819	2,566,553	4,867,990	165,839	9,230,593
MISHAP RATES (EVENTS per 100K HOURS)						
	A-7	A-10	F-15	F-16	F-117	ALL
100K Flying Hours	0.34392	15.95819	25.66553	48.6799	1.65839	92.30593
CFIT Rate	5.815305885	0.751964978	0.194813822	0.698440219	0.602994471	0.585011169
AF Pilot Fatality Rate	5.815305885	0.501309986	0.233776587	0.493016625	0.602994471	0.444175147
Total Fatality Rate	5.815305885	0.501309986	0.233776587	0.513558984	0.602994471	0.455008687
Destroyed Aircraft Rate	5.815305885	0.751964978	0.233776587	0.780609656	0.602994471	0.63917887

NOTES

1. As of 23 Feb 05, from AFSC/SERP
2. CFIT Mishaps include some PHYSIO and LOCI coded mishaps that could have been prevented by AGCAS
3. See CFIT LIST tab for complete list of all CFIT[3] mishaps considered
4. Costs in mishap year dollars

Fighter/Attack MIDAIR Mishap Summary FY 92-04						
	A-7	A-10	F-15	F-16	F-117	ALL
Total Class A Mishaps[1]	3	29	52	155	7	246
Total MIDAIR[2] Mishaps	0	3	7	21	0	31
MIDAIR AF Pilot Fatalities	0	2	2	6	0	10
MIDAIR Other Fatalities	0	0	0	25	0	25
Number Destroyed Aircraf	0	6	11	25	0	42
Total Mishap Cost[3]	$0	$61,910,607	$297,319,667	$508,699,863	$0	$867,930,137
Total Flying Hours[1]	34,392	1,595,819	2,566,553	4,867,990	165,839	9,230,593
MIDAIR MISHAP RATES (EVENTS per 100K HOURS)						
	A-7	A-10	F-15	F-16	F-117	ALL
100K Flying Hours	0.343920	15.95819	25.66553	48.6799	1.65839	92.30593
MIDAIR Rate	0.000000	0.187991	0.272739	0.431390	0.000000	0.335840
AF Pilot Fatality Rate	0.000000	0.12533	0.07793	0.12325	0.00000	0.10834
Total Fatality Rate	0.000000	0.12533	0.07793	0.63681	0.00000	0.37917
Destroyed Aircraft Rate	0.000000	0.37598	0.42859	0.51356	0.00000	0.45501

NOTES

1. As of 23 Feb 05, from AFSC/SERP
2. See MIDAIR LIST tab for complete list of all MIDAIR mishaps considered
3. Costs in mishap year dollars

USAF FLIGHT MISHAPS FY 92-04 ALL AIRCRAFT[1]	
Total Class A Mishaps	406
Total All Fatalities	362
Total Pilot Fatalities	126
Total Destroyed Aircaft	319
Total Flight Hours	29,491,960
FIGHTER/ATTACK (A-7, A-10, F-15, F-16, F-117) CFIT MISHAPS FY 92-04[2]	
Total Class A Mishaps	246
Total CFIT Mishaps	54
Total All CFIT Fatalities	42
Total Pilot CFIT Fatalities	41
Total CFIT Destroyed Aircraft	59
Total Flight Hours	9,230,593
FIGHTER/ATTACK vs USAF COMPARISONS (PERCENTAGES)	
F/A Class A Mishaps vs USAF Class A Mishaps	60.59%
F/A CFIT Mishaps vs USAF Class A Mishaps	13.30%
F/A CFIT Fatalities vs USAF All Fatalities	11.60%
F/A CFIT Pilot Fatalities vs USAF Pilot Fatalities	32.54%
F/A Destroyed Aircraft vs USAF Destroyed Aircraft	18.50%
F/A Flight Hours vs USAF Flight Hours	31.30%
NOTES	
1. USAF data from HQ USAF/XOOT (8 Mar 05)	
2. See FA CFIT Summary tab for breakout by MDS	

USAF FLIGHT MISHAPS FY 92-04 ALL AIRCRAFT[1]	
Total Class A Mishaps	406
Total All Fatalities	362
Total Pilot Fatalities	126
Total Destroyed Aircaft	319
Total Flight Hours	29,491,960
FIGHTER/ATTACK (A-7, A-10, F-15, F-16, F-117) MIDAIR MISHAPS FY 92-04[2]	
Total Class A Mishaps	246
Total MIDAIR Mishaps	31
Total All MIDAIR Fatalities	35
Total Pilot MIDAIR Fatalities	10
Total MIDAIR Destroyed Aircraft	42
Total Flight Hours	9,230,593
FIGHTER/ATTACK vs USAF COMPARISONS (PERCENTAGES)	
F/A Class A Mishaps vs USAF Class A Mishaps	60.59%
F/A MIDAIR Mishaps vs USAF Class A Mishaps	7.64%
F/A MIDAIR Total Fatalities vs USAF All Fatalities	9.67%
F/A MIDAIR Pilot Fatalities vs USAF Pilot Fatalities	7.94%
F/A Destroyed Aircraft vs USAF Destroyed Aircraft	13.17%
F/A Flight Hours vs USAF Flight Hours	31.30%
NOTES	
1. USAF data from HQ USAF/XOOT (8 Mar 05)	
2. See FA MIDAIR Summary tab for breakout by MDS	

FIGHTER/ATTACK (A-7, A-10, F-15, F-16, F-117) COMBINED CFIT AND MIDAIR MISHAPS FY 92-04	
Total Class A Mishaps	246
Total Combined CFIT and MIDAIR Mishaps	85
Total All Fatalities	77
Total Pilot Fatalities	51
Total Destroyed Aircraft	101
Total Flight Hours	9,230,593
Total Combined CFIT and MIDAIR Mishap Cost	$1,903,494,388
FIGHTER/ATTACK vs USAF COMPARISONS (PERCENTAGES)	
F/A Class A Mishaps vs USAF Class A Mishaps	60.59%
F/A Combined CFIT and MIDAIR Mishaps vs USAF Class A Mishaps	20.94%
F/A Combined CFIT and MIDAIR Fatalities vs USAF All Fatalities	21.27%
F/A Combined CFIT and MIDAIR Pilot Fatalities vs USAF Pilot Fatalities	40.48%
F/A Combined CFIT and MIDAIR Destroyed Aircraft vs USAF Destroyed Aircraft	31.66%
F/A Flight Hours vs USAF Flight Hours	31.30%
NOTES	
1. USAF data from HQ USAF/XOOT and AFSC (8 Mar 05)	

ATTACHMENT 3, USN/USMC F/A HISTORICAL DATA

USN/USMC Fighter/Attack CFIT and MIDAIR data broken down by Platform

USN/USMC Fighter/Attack CFIT Mishap Summary FY92-04	A-4	A-6E	AV-8B	EA-6B	F-5E	F-14	F-16N	F/A-18	ALL F/A
Total Class A Mishaps	3	11	51	16	4	53	2	109	249
Total CFIT Mishaps	0	2	2	4	1	4	1	19	33
CFIT USN/USMC Pilot Fatalities	0	2	2	2	1	2	1	16	26
CFIT Other Fatalities	0	2	0	24	0	5	0	1	32
Number CFIT Destroyed Aircraft	0	2	2	2	1	4	1	19	31
Total CFIT Mishap Cost (Aircraft Assets)	$0	$39,057,000	$37,738,000	$62,590,470	$3,795,000	$146,015,194	$11,482,000	$605,604,479	$906,282,143
Total Flying Hours	327,321	295,568	553,429	520,485	123,222	879,066	25,908	3,529,930	6,254,929
MISHAP RATES (EVENTS per 100K HOURS)	**A-4**	**A-6E**	**AV-8B**	**EA-6B**	**F-5E**	**F-14**	**F-16N**	**F/A-18**	**ALL F/A**
100K Flying Hours	3.27	2.96	5.53	5.20	1.23	8.79	0.26	35.30	62.55
CFIT Rate	0.00	0.68	0.36	0.77	0.81	0.46	3.86	0.54	0.53
USN/USMC Pilot Fatality Rate	0.00	0.68	0.36	0.38	0.81	0.23	3.86	0.45	0.42
Total Fatality Rate	0.00	1.35	0.36	5.00	0.81	0.80	3.86	0.48	0.93
Destroyed Aircraft Rate	0.00	0.68	0.36	0.38	0.81	0.46	3.86	0.54	0.50

USN/USMC Fighter/Attack MIDAIR Mishap Summary FY92-04	A-4	A-6E	AV-8B	EA-6B	F-5E	F-14	F-16N	F/A-18	ALL F/A
Total Class A Mishaps	3	11	51	16	4	53	2	109	249
Total MIDAIR Mishaps	0	3	2	0	1	3	0	11	20
MIDAIR USN/USMC Pilot Fatalities	0	1	1	0	0	2	0	5	9
MIDAIR Other Fatalities	0	1	0	0	0	1	0	2	4
Number MIDAIR Destroyed Aircraft	0	4	3	0	1	5	0	16	29
Total MIDAIR Mishap Cost (Aircraft Assets)	$0	$72,538,655	$55,250,814	$0	$2,336,960	$196,238,977	$0	$613,081,334	$939,446,740
Total Flying Hours	327,321	295,568	553,429	520,485	123,222	879,066	25,908	3,529,930	6,254,929
MISHAP RATES (EVENTS per 100K HOURS)	**A-4**	**A-6E**	**AV-8B**	**EA-6B**	**F-5E**	**F-14**	**F-16N**	**F/A-18**	**ALL F/A**
100K Flying Hours	3.27	2.96	5.53	5.20	1.23	8.79	0.26	35.30	62.55
MIDAIR Rate	0.00	1.01	0.36	0.00	0.81	0.34	0.00	0.31	0.32
USN/USMC Pilot Fatality Rate	0.00	0.34	0.18	0.00	0.00	0.23	0.00	0.14	0.14
Total Fatality Rate	0.00	0.68	0.18	0.00	0.00	0.34	0.00	0.20	0.21
Destroyed Aircraft Rate	0.00	1.35	0.54	0.00	0.81	0.57	0.00	0.45	0.46

USN/USMC Fighter/Attack CFIT Mishap Data Compared to All USN/USMC Class A Mishaps

USN/USMC FLIGHT MISHAPS FY92-04 ALL AIRCRAFT	
Total Class A Mishaps	442
Total All Fatalities	421
Total Pilot Fatalities	179
Total Destroyed Aircraft	385
Total Flight Hours	20,758,952
FIGHTER/ATTACK (A-4, A-6E, AV-8B, EA-6B, F-5E, F-14, F/A-18) CFIT MISHAPS FY92-04	
F/A Total Class A Mishaps	249
F/A Total CFIT Mishaps	33
F/A Total All Fatalities CFIT Mishaps	58
F/A Total Pilot Fatalities CFIT Mishaps	26
F/A Total Destroyed Aircraft CFIT Mishaps	31
F/A Total Flight Hours	6,254,929
F/A Total CFIT Mishap Cost (Aircraft Assets)	$906,282,143
FIGHTER/ATTACK vs. USN/USMC COMPARISONS (PERCENTAGES)	
F/A Class A Mishaps vs. USN/USMC Class A Mishaps	56.33%
F/A CFIT Mishaps vs. USN/USMC Class A Mishaps	7.47%
F/A CFIT Fatalities vs. USN/USMC All Fatalities	13.78%
F/A CFIT Pilot Fatalities vs. USN/USMC Pilot Fatalities	14.53%
F/A CFIT Destroyed Aircraft vs. USN/USMC Destroyed Aircraft	8.05%
F/A Flight Hours vs. USN/USMC Flight Hours	30.13%

ATTACHMENT 4, USAF F/A PILOT STUDY ABSTRACT

MAPES, P., Air Force Research Laboratory, *Controlled Flight Into Terrain & Mid-Air Collisions, Pilot Experience, Recency & Tactical Change*, **Overview:** Controlled Flight Into Terrain (CFIT) and Mid-Air Collisions (MAC) together were responsible for 85 of 246 (34.6%) USAF fighter/attack (F/A) class A mishaps for the period of FY 1992 to FY 2004. These mishaps destroyed 101 aircraft and killed 77 people. In fact, in both the U.S. Navy and the USAF, CFIT alone accounts for 20% of all class A mishaps and nearly 40% of all fatalities. A solution to both of these problems would cut fatalities in F/A aircraft by over 50% and reduce the F/A class A mishap rate by more than one third. This would go a long way toward meeting Secretary of Defense Rumsfeld's 2003 instruction to reduce mishaps by 50% although the implementation would take longer than the directed 2 year period. **Purpose:** This study compares the recency and total flight experience of all USAF F/A pilots with the recency and total flight experience of USAF F/A pilots involved in both class A CFIT and MAC mishaps to determine if there is any discernable predilection toward inexperience or lack of recency. The study also compares the CFIT rates of F-16 pilots before and after the cessation of low altitude weapon delivery training to determine if stopping that training had a significant effect on Class A CFIT mishaps in the F-16 fleet. **Methods:** HQ USAF XOOT provided a database for the denominator of all USAF pilots compiled in 2004 which allowed stratification of pilots by weapon system, total time and 90-day recency. These results were compared to those found among a population of pilots obtained from the USAF Safety Center who were involved in either class A CFIT or MAC mishaps. Since the experience and recency data of the denominator should be representative of the pilots from whom the numerator data was derived, a modified Taylor series analysis was applied to compare the data in each cell. In the case of the change in F-16 tactics, the populations of USAF F-16 mishaps and F-16 flight hours from FY 1993 to 2003 was stratified into two groups including those from FY 1993 to FY 1998 and those from FY 1999 to FY 2003. The mishap rates of the two groups were compared statistically using an unmodified Taylor Series and a "p-value" was computed to determine the likelihood that any difference between the two groups occurred by chance. **Results:** No association was found between 90-day currency or total hours and the likelihood that a pilot would be involved in either a spatial disorientation (SD) CFIT or MAC mishap. In the F-16 tactics data, the slight decrease in the F-16 CFIT rate of .086/100Khrs. after FY 1998 was found to have most likely occurred by chance alone, $p=.72$. **Discussion:** The inability to demonstrate any effect from either 90-day recency or total time on the CFIT or MAC class A mishaps of the USAF suggests that no measurable benefit occurs from either recency or experience. The fact that Bushby et al demonstrated value with respect to the lowering of CFIT mishap rates among British military pilots with increasing pilot experience begs the question of why a similar effect was not isolated in the USAF F/A community. The answer may be that Bushby's data does not correct for the distribution of pilot experience in the underlying force. Another hypothetical answer may be found in the amount of training received by the pilots in the services of the two countries. British pilots receive roughly 11 hours of training aimed at preparing them to survive an encounter with SD while USAF pilots receive 50 hours of this sort of instruction. It is completely possible that the instruction received by the USAF pilots is adequate to effectively prophylax them against any mishap predisposition from lack of total experience. A potential way to validate this supposition would be to provide the USAF SD training to ab initio British pilots and see if there is a measurable decline in the mishap rate approaching the results seen in

the United States. In the F-16 community, deleting the requirement for low altitude iron bomb delivery does not seem to have had an appreciable effect on SD mishap rates. The conversion to smart weapons has not resulted in a corresponding decline in the CFIT rate of the F-16. It is entirely possible that the risk factor for F-16 SD is simply the time spent in the low or medium altitude environment. **Conclusion:** Increasing 90-day recency, total time, or the cessation of the use of iron bombs in the F-16 has had no effect on USAF F/A class A CFIT rates. Increasing 90-day recency or total time had no effect on USAF F/A MAC rates. Only automated systems have been shown to adequately prevent ground impact during SD episodes. The only fully tested system showing value for the mitigation of CFIT mishaps so far is the Automatic Ground Collision Avoidance System (Auto-GCAS). If a F/A pilot places the aircraft in a position that will result in impact with the earth, Auto-GCAS disengages the pilot from the controls and flies a 5 Gz recovery to save the aircraft and the pilot. This system has been tested on over 2,200 occasions using actual mishap scenarios. The only USAF system available in the near future to prevent class A MAC is the Automatic Airborne Collision Avoidance System (Auto-ACAS). This system is also completely automatic and does not require any input from the pilot. It is estimated to be 75% effective at preventing USAF F/A MAC. Both systems are only candidates for installation in aircraft with digital electronic flight controls. In the F/A-22, F-35 & F-16 aircraft, they have the potential to preserve 140 aircraft and 117 lives over the remaining fleet service lives. **Disclaimer:** The opinions expressed herein are those of the author and do not represent the opinions of any other person or organization.

ATTACHMENT 5, USAF AUTO-CAS PROJECTIONS

F-16 CFIT AND MIDAIR MISHAP PROJECTIONS FOR FY 11-25			
	CFIT	MIDAIR	
Protected Exposure 100K Hours[1,5]	22.32000	22.32000	
Exposure Hours Adjusted For ACAS System Effectiveness[2]	21.87360	16.74000	
F-16 Class A CFIT or MIDAIR Mishap Rate[3]	0.698440219	0.431390000	
Pilot Fatality Rate[3]	0.493016625	0.123250000	
Total Fatality Rate[3]	0.513558984	0.636810000	
Destroyed Aircraft Rate[3]	0.780609656	0.513560000	
Projections FY 11-25	CFIT	MIDAIR	CFIT + MIDAIR
Total Class A Mishaps Prevented	15.3	7.2	22.5
Total Pilots Saved	10.8	2.1	12.8
Total Fatalities Saved	11.2	10.7	21.9
Total Aircraft Saved	17.1	8.6	25.7
Total Mishap Costs Saved[1,4]	$614,690,761	$309,491,798	$924,182,560
NOTES			
1. Data provided by AFRL/HE based on SPO estimates for service life of current F-16s			
2. Assumes AGCAS 98% effective and AACAS 75% effective			
3. See USAF_FY92_04_CFIT_Midair.xls			
4. Assumes replacement cost of $35M/aircraft loss and $1M damage			
5. Assumes 50% effectiveness over install period of FY 11-12			

F/A-22 CFIT+MIDAIR MISHAP PROJECTIONS FOR FY 11-35						
	CFIT	MIDAIR				
Protected Exposure 100K Hours[1,5]	17.32901	17.32901				
Exposure Hours Adjusted For ACAS System Effectiveness[2]	16.98243	12.99676				
Blends - F-15/F-16	90/10			80/20		
	CFIT	MIDAIR		CFIT	MIDAIR	
Mishap Rate[3]	0.282476108	0.300354343		0.356807713	0.323769962	
Pilot Fatality Rate[3]	0.278900461	0.085815527		0.317162411	0.092505703	
Total Fatality Rate[3]	0.282476108	0.175206700		0.323769962	0.257694459	
Destroyed Aircraft Rate[3]	0.328959519	0.443380221		0.409668115	0.455920966	
Projections FY 11-35	CFIT	MIDAIR	CFIT + MIDAIR	CFIT	MIDAIR	CFIT + MIDAIR
Total Class A CFIT or MIDAIR Mishaps Prevented	4.8	3.9	8.7	6.1	4.2	10.3
Total Pilots Saved	4.7	1.1	5.9	5.4	1.2	6.6
Total Fatalities Saved	4.8	2.3	7.1	5.5	3.3	8.8
Total Aircraft Saved	5.6	5.8	11.3	7.0	5.9	12.9
Total Mishap Costs Saved[4]	$692,729,959	$714,550,646	$1,407,280,605	$862,687,840	$734,761,286	$1,597,449,125
Blends - F-15/F-16	70/30			60/40		
	CFIT	MIDAIR		CFIT	MIDAIR	
Mishap Rate[3]	0.420634537	0.343876410		0.476036468	0.361328885	
Pilot Fatality Rate[3]	0.350017060	0.098250403		0.378535022	0.103236824	
Total Fatality Rate[3]	0.359228036	0.328524785		0.390005781	0.390005781	
Destroyed Aircraft Rate[3]	0.478970714	0.466689414		0.539125638	0.476036468	
Projections FY 11-35	CFIT	MIDAIR	CFIT + MIDAIR	CFIT	MIDAIR	CFIT + MIDAIR
Total Class A CFIT or MIDAIR Mishaps Prevented	7.1	4.5	11.6	8.1	4.7	12.8
Total Pilots Saved	5.9	1.3	7.2	6.4	1.3	7.8
Total Fatalities Saved	6.1	4.3	10.4	6.6	5.1	11.7
Total Aircraft Saved	8.1	6.1	14.2	9.2	6.2	15.3
Total Mishap Costs Saved[4]	$1,008,626,729	$752,115,693	$1,760,742,422	$1,135,302,249	$767,179,386	$1,902,481,635
Blends - F-15/F-16	50/50			F/A-22 = F-15A/B/C/D/E		
	CFIT	MIDAIR		CFIT	MIDAIR	
Mishap Rate[3]	0.524578310	0.376620325		0.194813822	0.272739	
Pilot Fatality Rate[3]	0.403521777	0.107605807		0.233776587	0.07793	
Total Fatality Rate[3]	0.416972503	0.443873954		0.233776587	0.07793	
Destroyed Aircraft Rate[3]	0.591831939	0.484226132		0.233776587	0.42859	
Projections FY 11-35	CFIT	MIDAIR	CFIT + MIDAIR	CFIT	MIDAIR	CFIT + MIDAIR
Total Class A CFIT or MIDAIR Mishaps Prevented	8.9	4.9	13.8	3.3	3.5	6.9
Total Pilots Saved	6.9	1.4	8.3	4.0	1.0	5.0
Total Fatalities Saved	7.1	5.8	12.9	4.0	1.0	5.0
Total Aircraft Saved	10.1	6.3	16.3	4.0	5.6	9.5
Total Mishap Costs Saved[4]	$1,246,292,301	$780,377,832	$2,026,670,132	$492,291,715	$690,715,416	$1,183,007,131

NOTES

1. Data provided by AFRL/HE based on SPO estimates of F/A-22 service life
2. Assumes AGCAS 98% effective and AACAS 75% effective
3. Rates are blend of F-15 and F-16 numbers from FA-22 CFITand FA-22 MIDAIR tabs
4. Assumes replacement cost of $120M/aircraft loss and $4M damage
5. Assumes 50% effectiveness over install period of FY 11-12

F-35 CFIT+MIDAIR MISHAP PROJECTIONS FOR FY 11-35						
	CFIT	MIDAIR				
Protected Exposure 100K Hours[1]	88.83418	88.83418				
Exposure Hours Adjusted For ACAS System Effectiveness[2]	87.05750	66.62564				
Blends - F-16/A-7+A-10	90/10			80/20		
	CFIT	MIDAIR		CFIT	MIDAIR	
Mishap Rate[3]	0.704192483	0.422515490		0.710827336	0.412279855	
Pilot Fatality Rate[3]	0.497335941	0.123233684		0.502317984	0.123210072	
Total Fatality Rate[3]	0.517141354	0.618369024		0.521273380	0.597094962	
Destroyed Aircraft Rate[3]	0.783414137	0.508338948		0.786648919	0.502317984	
Projections FY 11-35	CFIT	MIDAIR	CFIT + MIDAIR	CFIT	MIDAIR	CFIT + MIDAIR
Total Class A CFIT or MIDAIR Mishaps Prevented	61.3	28.2	89.5	61.9	27.5	89.4
Total Pilots Saved	43.3	8.2	51.5	43.7	8.2	51.9
Total Fatalities Saved	45.0	41.2	86.2	45.4	39.8	85.2
Total Aircraft Saved	68.2	33.9	102.1	68.5	33.5	102.0
Total Mishap Costs Saved[4]	$2,734,903,143	$1,358,123,050	$4,093,026,193	$2,746,195,785	$1,342,036,912	$4,088,232,697
Blends - F-16/A-7+A-10	70/30			60/40		
	CFIT	MIDAIR		CFIT	MIDAIR	
Mishap Rate[3]	0.718564786	0.400343238		0.727704587	0.386243204	
Pilot Fatality Rate[3]	0.508127956	0.123182535		0.514990938	0.123150007	
Total Fatality Rate[3]	0.526092075	0.572285526		0.531784121	0.542979576	
Destroyed Aircraft Rate[3]	0.790421265	0.495296442		0.794877318	0.487002300	
Projections FY 11-35	CFIT	MIDAIR	CFIT + MIDAIR	CFIT	MIDAIR	CFIT + MIDAIR
Total Class A CFIT or MIDAIR Mishaps Prevented	62.6	26.7	89.2	63.4	25.7	89.1
Total Pilots Saved	44.2	8.2	52.4	44.8	8.2	53.0
Total Fatalities Saved	45.8	38.1	83.9	46.3	36.2	82.5
Total Aircraft Saved	68.8	33.0	101.8	69.2	32.4	101.6
Total Mishap Costs Saved[4]	$2,759,365,065	$1,323,277,542	$4,082,642,607	$2,774,921,173	$1,301,118,184	$4,076,039,357
Blends - F-16/A-7+A-10	50/50			F-16 = F-35		
	CFIT	MIDAIR		CFIT	MIDAIR	
Mishap Rate[3]	0.738665978	0.369332989		0.698440219	0.431390	
Pilot Fatality Rate[3]	0.523221735	0.123110996		0.493016625	0.12325	
Total Fatality Rate[3]	0.538610609	0.507832860		0.513558984	0.63681	
Destroyed Aircraft Rate[3]	0.800221477	0.477055111		0.780609656	0.51356	
Projections FY 11-35	CFIT	MIDAIR	CFIT + MIDAIR	CFIT	MIDAIR	CFIT + MIDAIR
Total Class A CFIT or MIDAIR Mishaps Prevented	64.3	24.6	1582.4	60.8	28.7	89.5
Total Pilots Saved	45.6	8.2	53.8	42.9	8.2	51.1
Total Fatalities Saved	46.9	33.8	80.7	44.7	42.4	87.1
Total Aircraft Saved	69.7	31.8	101.4	68.0	34.2	102.2
Total Mishap Costs Saved[4]	$2,793,577,661	$1,274,542,398	$4,068,120,059	$2,725,112,685	$1,372,069,357	$4,097,182,042
Blends - F-16/A-7+A-10	ALL F-16+A-7+A-10					
	CFIT	MIDAIR				
Mishap Rate[3]	0.738665978	0.369332989				
Pilot Fatality Rate[3]	0.523221735	0.123110996				
Total Fatality Rate[3]	0.538610609	0.50783286				
Destroyed Aircraft Rate[3]	0.800221477	0.477055111				
Projections FY 11-35	CFIT	MIDAIR	CFIT + MIDAIR			
Total Class A CFIT or MIDAIR Mishaps Prevented	64.3	24.6	88.9			
Total Pilots Saved	45.6	8.2	53.8			
Total Fatalities Saved	46.9	33.8	80.7			
Total Aircraft Saved	69.7	31.8	101.4			
Total Mishap Costs Saved[4]	$2,793,577,661	$1,274,542,398	$4,068,120,059			

NOTES

1. Data provided by AFRL/HE based on JPO estimates for F-35 service life
2. Assumes AGCAS 98% effective and AACAS 75% effective
3. Rates are blend of F-16, A-7, and A-10 numbers from F-35 CFITand F-35 MIDAIR tabs
4. Assumes replacement cost of $38.1M/aircraft loss and $2M damage

ATTACHMENT 6, USN/USMC AUTO RECOVERY PROJECTIONS

F/A-18 CFIT MISHAP PROJECTIONS FOR FY08-32

F/A-18 CFIT MISHAP PROJECTIONS FOR FY08-32			
	CFIT	PHYSIO	TOTAL
Projected Exposure 100K Hours[1]	46.2	46.2	46.2
F/A-18 Class A CFIT Mishap Rate (FY92-04)[2]	0.37	0.17	0.54
Pilot Fatality Rate (FY92-04)[2]	0.34	0.11	0.45
Total Fatality Rate (FY92-04)[2]	0.37	0.11	0.48
Destroyed Aircraft Rate (FY92-04)[2]	0.37	0.17	0.54
F/A-18 Projected Class A CFIT Mishap Rate with TAWS[3]	0.18	0.17	0.35
Pilot Fatality Rate (FY92-04)[3]	0.17	0.11	0.28
Total Fatality Rate (FY92-04)[3]	0.18	0.11	0.30
Destroyed Aircraft Rate (FY92-04)[3]	0.18	0.17	0.35
F/A-18 Projected Class A CFIT Mishap Rate with Auto Recovery[4]	0.15	0.03	0.18
Pilot Fatality Rate (FY92-04)[4]	0.14	0.02	0.16
Total Fatality Rate (FY92-04)[4]	0.15	0.02	0.17
Destroyed Aircraft Rate (FY92-04)[4]	0.15	0.03	0.18
Projections FY08-32	**CFIT**	**PHYSIO**	**TOTAL**
Total Class A Mishaps Prevented	**1.7**	**6.3**	**8.0**
Total Pilots Saved	**1.6**	**4.2**	**5.8**
Total Fatalities Saved	**1.7**	**4.2**	**5.9**
Total Aircraft Saved	**1.7**	**6.3**	**8.0**
Total Mishap Costs Saved[5]	**$137,452,178**	**$507,515,734**	**$644,967,912**
NOTES			
1) Data provided by PMA265			
2) Based on Historical data from Naval Safety Center.			
3) Projected CFIT rate after introduction of TAWS in FY04			
4) Projected CFIT/PHYSIO rates after introduction of Auto Recovery in FY15			
5) Assumes replacement cost of F/A-18E/F: $80.8M			

ATTACHMENT 7, USN/USMC CFIT RATE BY PLATFORM

The following charts present Naval Safety Center data for two time periods. The Navy has been fielding GPWS systems since the late 1980's, and the data shows a correlating shift in CFIT mishap rates after GPWS is installed, including the F/A-18 and AV-8B. The data presented shows CFIT mishap rates per 100,000 flight hours for various Navy/Marine Corps aircraft.